AB-267 DYNAMICS & CONTROL OF FLEXIBLE AIRCRAFT

LECTURE NOTES

SYLLABUS
Summary

AB-267 DYNAMICS AND CONTROL OF FLEXIBLE AIRCRAFT

Recommended: AB-103 / MVO-30 (Aircraft Stability and Control)

Weekly dedication: 3h classes, 6h homework & learning

AB-267 DYNAMICS AND CONTROL OF FLEXIBLE AIRCRAFT

- Midterm exam #1 (50%) + list(s) of exercises (50%)
- Midterm exam #2 (50%) + list(s) of exercises (50%)
- Final exam (100%)

Collaboration: knowledge exchange with classmates is highly encouraged. HOWEVER, each student shall write down his or her own solutions. Copy of solutions or codes from others is prohibited!!!
Bibliography


Work plan

- Introduction
- (Supersonic) review of systems of reference, RB flight dynamics & aeroelasticity
- Definition of mean axes
- Structural dynamics and modal superposition
- EoM of flexible aircraft applying Lagrangian mechanics, under small deformations
- 2D aerodynamics and strip theory
- QS and unsteady aerodynamic loads due to aircraft deformation
- Simulation of flexible aircraft programming EoM in MATLAB
- Trimming and linearisation, stability analysis
- Aeroelastic oscillation suppression
- Sensor positioning and aeroservoelastic stability
- Flexibility-driven PIO
Introduction

What is a FLEXIBLE aircraft?
Introduction

Helios: a prototype of a HALE aircraft powered by solar energy

“Thirty minutes into the flight the aircraft again encountered normal turbulence and then experienced an unexpected, persistent high wing dihedral configuration. As a result, the aircraft became unstable as pitch oscillations grew. Airspeed deviated from the normal flight speed, and the deviations grew with every cycle of the oscillation, soon exceeding the aircraft’s design speed. The resulting high dynamic pressures caused the wing’s outer wing panels to fail and the solar cells and skin on the upper surface to rip off.”

https://www.youtube.com/watch?v=1NCOPLEJOlo0 (look at 1’50”)
Introduction

X-HALE: flexible prototype for flight testing, developed at UMich (Prof. Cesnik) - currently being reproduced at ITA

https://www.youtube.com/watch?v=QSZxoANusHU
Introduction

Does it apply only to HALE or small aircraft?
Introduction

Boeing 787 dreamliner

https://www.youtube.com/watch?v=StQneURTciU

IMAGE CREDITS: BOEING
Introduction

Is that a new phenomenon?
Introduction

Sailplane DG-300

https://www.youtube.com/watch?v=kQl3AWpTWhM
Introduction

Wright 1902 aircraft, Wright brothers
- warping wings to generate roll (inspired on birds)
Introduction

Why does the flexibility increase?
Introduction

Why does the flexibility increase?

- Breguet equation of range in cruise

\[
R = \sqrt{\frac{2}{\rho S \text{TSFC}} \frac{C_L^{1/2}}{C_D}} \left( \sqrt{W_i} - \sqrt{W_f} \right)
\]

- fly at higher altitudes
- more efficient engines
- reduce drag for a given lift
- increase AR!
Introduction

What consequences does the increase in flexibility bring?

some examples…
Introduction

Frequency separation band gets tighter >> stability concerns

Drewiacki, Silvestre, Guimarães Neto, AIAA 2016* (accepted)

increase in flexibility


dutch roll

elastic modes
Introduction

Handling qualities - PIO due to airframe flexibility

Drewiacki, Silvestre, Guimarães Neto, AIAA 2016* (accepted)
AEROSEROVOELASTIC stability

- control law may interact with elastic modes

Introduction

Root Locus (sensor at P2)

- \( K_r = 0.1 \)
- \( K_r = 1.0 \)
- Modes: 16, 14, 12, 8, 5, 2
- Aerodynamic lags, short period, dutch roll
Introduction

FCL design: stability margin & performance reduction

**DECOUPLED FCL DESIGN**

**COUPLED FCL DESIGN**

Silvestre et al, Journal of Aircraft 2016 (submitted)
Convinced that flexibility matters?
We are...

- X-HALE is currently under construction at ITA
- validation of integrated models with different levels of complexity (moderately and highly flexible AC)
- coupling of AE and FM modes
- new techniques for control without notch filters — AE in the loop

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Some advertising :)
Desirable background

Let’s first quickly review some topics you may need during the course

- Reference systems & transformation matrices
- RB flight mechanics
- Aeroelasticity
1st list of exercises

Solve exercises 2.1, 2.2, 2.9 of


Due: next Thursday, March 4th